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DESIGN AND FABRICATION OF TEST RIG TO DETERMINE HELIUM PERMEABILITY THROUGH FABRIC

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ABSTRACT

The fabric of an envelope of Lighter-Than-Air (LTA) systems experiences permeation of LTA gas (usually Helium or Hydrogen) over a period of time. The permeation occurs due to intermolecular spaces in the structure of the fabric, e.g., PVC, PVC coated Nylon, Metalized polymer. This paper describes the design of a test rig to determine the permeability of Helium gas through the fabric. This rig consists of an upper and lower chamber arranged to hold a fabric specimen in between them. A pressurized Helium gas cylinder is connected to the lower chamber through a pressure regulator. A heater is also attached to the lower chamber and a temperature sensor is used to measure the temperature of the test specimen. A Helium leak detector is coupled to the upper chamber to detect the amount of Helium permeated over a period of time. The key objective of this study is to develop and test a robust and reliable permeability tester for characterizing the envelope material.

KEYWORDS: Gas Permeability Tester, Helium Leak Detector, Fabric Characterization & LTA Systems

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Original Article

INTRODUCTION

The permeability rate of fabric should be known in order to determine the flight duration of an airship. The application such as communication satellite, deployed communication relay, surveillance uses aerostat and air ship, major problems they face are Helium permeability which affects the determination of actual deployment duration. Noll [1] observed the leakage in the airship fabric which reduces the duration of flight and leak caused by defects in fabric and also concluded that the improvement is required for a leak testing. Ashford et al.[2]had followed ASTM std. D1434 and they concluded that most of the Helium loss in the aerostat is due to the permeability that also high during hot climate. Fernandes et al. [3] had studied that the LTA system experience leakage continuously due to the presence of pinholes and scratch on the fabric. They have used Helium mass spectrometer as a detection unit and they found that the average permeability of fabric is around 3.00l / m^2 / day and to avoid the leakage of Helium gas by other means they used the sealant Loctite 577 and entire experiment followed under the ASTM std. D1434.

Kammermeyer and Brubaker [4] used the design in which they have used two chamber one is the upper chamber and the other is lower chamber and fabric was clamped between these chambers by means of C clamp mechanism. In order to determine permeability, Doyle [5] had used the gas flow method in which permeate gas pressure was monitored by the residual gas analyzer and the material used for fabricating test chamber was Stainless Steel. Yao et al. [6] studied that the fabric used in aerostat consists of three different layers i.e. protected layer, load carrier, Helium barrier with different structure and composites. They found that the diffusion of Helium is only along the direction perpendicular to the area of the specimen.

Figure 1: IIT Bombay (Aerospace Dept.).

Van et al. [7] in his experiment had used the test specimen of 45 mm diameter is clamped between the test chamber and attached to a Helium leak detector (Leybold L200). Crosby [8] coated fabric with petroleum jelly and beeswax to seal the peripheral area of the material and used a porous plate to avoid stretching and relaxation of fabric.

The Lighter-Than-Air (LTA) systems laboratory of IIT Bombay has been involved in design fabrication and field testing of airships and aerostats for last two decades. One of the problems that is regularly encountered in such systems is the leakage of lifting gas through the envelope, making it very difficult to predict the effective deployment duration. To address this problem, they need a test rig which can determine the permeability rate of lifting gas through the envelope fabric. This paper describes the design of a test rig for determination of permeability of Helium gas through a fabric sample.

METHODS

Figure 2 shows the schematic of a test rig, In which two chambers have been shown in between fabric is clamped and gas will permeate through the fabric by means of pressure difference in both chambers. The gas will permeate from the lower chamber to the upper chamber and then the concentration of permeated gas will be detected by the leak detecting device. Along with that we have taken into consideration the temperature and pressure variation. As per the requirement different components have been selected as follows.

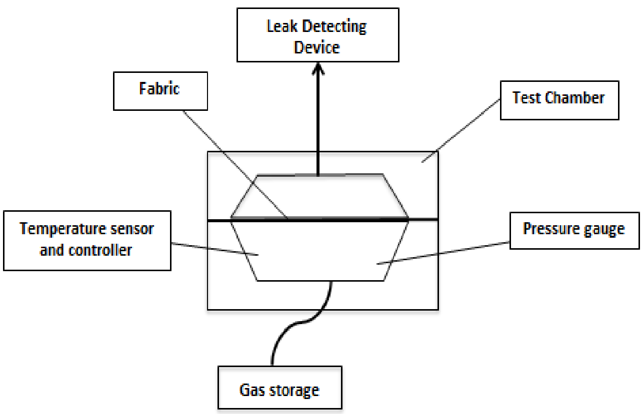

Figure 2: Schematic Diagram.

Figure 3: Helium Leak Detector.

Helium Leak Detector

The Oerlikon Leybold Vacuum Phoenix L300i as seen in Figure 3 is a Helium leak detector. It is an instrument commonly used to detect and locate small leaks. As gas will permeate to the upper chamber the mass spectrometer probe will be connected to the outlet of the upper chamber. Typically a Helium leak detector will be used to measure leaks in the range of 10^{-5} to 10^{-12} Pa.m^3.s^{-1} Once the HLD is switched on, it.

DESIGN OF THE TEST CHAMBER

Temperature Variation

Permeability of gas is determined in different temperature conditions, it is very important to take a temperature effect in consideration because it causes the change in velocity and density of the gas which affects the permeability. Also temperature gradient changes the structure of polymer, for that heating element, temperature sensor and temperature controller has been used. So that it is concluded that the permeability is affected due to change in temperature.

Pressure Variation

Pressure gradient is a driving force causing the gas flow through the polymer. Pressure variation should be considered for different applications for which polymer is to be used. The pressure in the lower chamber will be slightly greater than the atmospheric pressure.

Volume Consideration

The standard permeability rate for any fabric is around 3.00 L / m^2/ day as mentioned in research papers. So while designing the chamber volume is taken into account. The volume of lower chamber was kept more than the upper chamber so that it is ensured that there is always gas present for permeation to take place.

Sealing Method

Since Helium is mono-atomic gas so probabilities of leakage of the Helium gas is very high. So the gasket made up of butyl rubber has been used and to ensure that no leakage from any mechanical mating, a sealant is used.

- In addition, few considerations were taken in the design of the test rig as follows,
- The porous plate (SS 316) is placed below the fabric to avoid the sudden impact of gas on the fabric and to avoid deformation of the fabric.

- Helium gas permeates only through fabric not through any other area of the chamber.
- Pressure difference will remain constant

  i.e. ΔP = Constant.
- Leakage has been prevented from all the mechanical assemblies.

The maximum rate of permeability of fabric is around 3.00 L / m^2/ day according to the paper presented by Fernandes et al. [3]. Based on this standard permeation rate, chamber design has been done. To take care of differential pressure between two chambers, the volume of the upper chamber per area of the specimen was kept 5.00 L/ m^2 and that of the lower chamber was kept 8.00 L/m^2.

From reference books [14] the standard material selection for bolts and nuts selected as 40Ni14 Alloy steel. The stresses acting on the bolt is pre-tension and torsional stress. Since the weak area is the threads, from Maximum Shear Stress theory the induced shear stress is less than the material allowable shear strength. Due to the pre-tension in the bolt stress is induced in the threads in the form of shear and crushing. After calculating, the induced stress was found less than the strength of the bolt.

It was seen that the leakage of Helium through Stainless steel 316 was negligible and also the selection is supported by Doyle [5]. The material of the chamber is selected on the above criteria. Due to the pre-tensioning of the bolts a compressive force is induced in the upper and lower chamber surface due to nut and bolt head, on checking the induced stress on the chamber surfaces with the strength of SS 316 the material is not affected. The function of the O-ring is to provide a perfect bed to clamp the fabric. Due to clamping, compressive stress is induced on it which on checking with the strength provides a safe selection.

The entire test chamber is provided with a four leg stand with a clamping setup. The induced load on the leg is the weight of the entire test rig and basis of the above compressive load and the strength of cast iron selected for the four legged stand the required dimensions is found. Clamping force of the nut causes compression of the plate of the table which helps to select the thickness of the plate of the four legged tables.

The fabric to be tested is clamped in between the upper and the lower chamber. Clamping of the fabric with chamber is done by Nuts and Bolts Mechanism. Further Helium gas through the Helium gas cylinder is passed at desired pressure. The pressure of the gas is the lower chamber is maintained with the help of the pressure regulator. Due to pressure and LTA property of Helium gas, it will diffuse to the upper chamber. To maintain the uniform distribution of the Helium on the specimen, the gas is made to flow through the porous plate placed below the fabric. The amount of gas present in the upper chamber is measured using the Helium Leak Detector. The Helium Leak Detector will sense Helium in the upper chamber and shows the quantity of Helium in ppm. One of the objectives of this study is to check the effect of temperature on the permeation rate of Helium through fabrics to be tested. So to achieve the variation in the temperature inside the chamber, a heater is used. In the lower chamber, the heater is in contact with the porous plate, and the porous plate is in contact with the O Ring on which the specimen was placed. Because of heat transfer, the temperature of the fabric will be increased. The temperature of the heater is controlled using the PID controller and the temperature is varied as per the required temperature of the fabric to be tested which is detected by the RTD (Resistance Temperature Detector) temperature sensor in contact with the fabric.

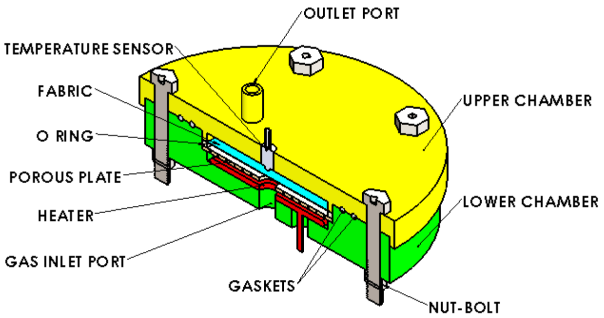

Figure 4: Sectional 3D Model.

Figure 5: Test Rig.

Before supplying the gas to the lower chamber we check the Helium present in the upper chamber since some percentage of Helium is also present in the air. After the experiment for a certain duration, the concentration of Helium will be checked in the upper chamber. The difference in the presence of the Helium concentration gives the permeability of that fabric.

A specimen of diameter 100mm has been cut as per the ISO: 15105 testing standards. A continuous supply of Helium is given at a fixed input pressure, at ambient temperature conditions after a certain time period. The concentration of Helium permeated is measured by the Helium Leak Detector in parts per million.4 specimens were tested for a time range varying from 1 hour to 6 hours, and readings were taken accordingly.

RESULTS

$$\text{Permeability} = \left\{\left(\frac{X}{T}\right) \times 12 \times 10^{-5}\right\} L / m^2 / day$$

Where, X: Concentration of helium in ppm.

T: Experiment duration (hrs)

The above equation has been obtained from the definition of parts per million and using standard value at NTP as 1 mole of gas = 25.12 L

Table 1: Permeation Rate of Test Specimen 1 (White PVC) under Given Input Conditions

SPECIMEN DETAILS		INPUT CONDITIONS			PERMEATION RATE	
Name	GSM	Temperature	Input Pressure	Supply duration (in hours)	(in ppm) (*10^4)	L/m^2/day
WHITE PVC	178	32	15 psi	1	3.5	4.2
		31	15 psi	2	4.3	2.58
		32	15 psi	3	5.1	2.04
		34	15 psi	4	6.6	1.98
		31	15 psi	5	14.4	3.456

Table 2:Permeation Rate of Test Specimen 2 (PU Coated Nylon) under Given Input Conditions

SPECIMEN DETAILS		INPUT CONDITIONS			PERMEATION RATE	
Name	GSM	Temperature	Input Pressure	Supply duration (in hours)	(in ppm) (*10^4)	L/m^2/day
PU COATED NYLON	253	32	15 psi	1	1.1	1.32
		31	15 psi	2	2.1	1.26
		31	15 psi	3	3	1.2
		30	15 psi	4	3.1	0.93
		31	15 psi	5	5.6	1.344
		32	15 psi	6	7.2	1.44

Table 3: Permeation Rate of Test Specimen 3 (MPET) under Given Input Conditions

SPECIMEN DETAILS		INPUT CONDITIONS			PERMEATION RATE	
Name	GSM	Temperature	Input Pressure	Supply duration (in hours)	(in ppm) (*10^4)	L/m²/day
MPET	80	29	15 psi	1	2.4	2.88
		31	15 psi	2	3.4	2.04
		31	15 psi	3	4.8	1.92
		30	15 psi	4	7.4	2.22
		31	15 psi	5	9.2	2.208
		30	15 psi	6	7.8	1.56

Table 4: Permeation Rate of Test Specimen 4 (Flexible Yellow PVC) under Given Input Conditions

SPECIMEN DETAILS		INPUT CONDITIONS			PERMEATION RATE	
Name	GSM	Temperature	Input Pressure	Supply duration (in hours)	(in ppm) (*10^4)	L/m²/day
FLEXIBLE YELLOW PVC	387	30	15 psi	1	1.8	2.16
		32	15 psi	2	2.1	1.26
		33	15 psi	3	3.5	1.4
		31	15 psi	4	7.5	2.25
		32	15 psi	5	6.5	1.56
		32	15 psi	6	11	2.2

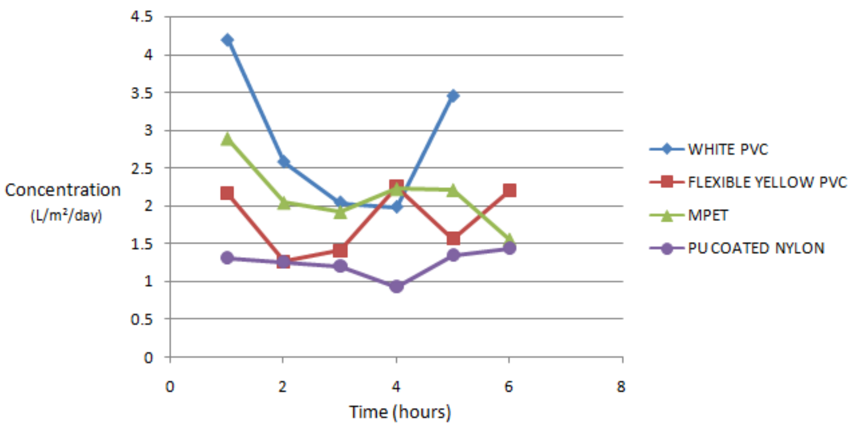

Figure 6: Line Graph Time vs Concentration of Helium of all Test Specimen.

As per the objective different method has been studied that can measure the permeability of the Helium through the fabric.

Here the Test Rig has been successfully designed and modeled, considering all the constraints. The chamber has been designed keeping in mind the effect of temperature and pressure variation on fabric. By using this test rig one can find the permeability rate of Helium for any fabric and can use it for various applications according to its chemical and physical properties. Along with that the leakage of Helium gas through the chamber has been minimized to negligible amount. Permeation rates varied between 1.249 L/m^2/day to 2.443 L/m^2/day for PU coated Nylon to White PVC respectively. PU coated Nylon showed the least permeability.

CONCLUSIONS

- The test rig has been successfully designed, modeled, fabricated and tested, considering all the constraints.
- By using this test rig one can find the permeability rate of Helium for any fabric and can use it for various applications according to its chemical and physical properties.
- The leakage has been minimized from the Test rig.
- In an attempt to address the problem at hand, an insightful understanding in the domain of gas permeation was attained by the team. Further, an opportunity to practically implement the design skills taught in the classroom kept the team motivated.
- The work and thus, the learning is still ongoing, and further efforts shall be made to further improve the system after due testing.

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REFERENCES

1. *J. R. Noll, "Determination of Lift Gas Leakage Rate for a Stratospheric Airship Hull," 11th ATIO Conference-19th LTA SYSTEM, Conference, Virginia Beach, sept. 22, 2011, Serial No. 78228.*
2. *R. L. Ashford, B. T. Bata and E. D. Walsh, "Measurement of Helium gas transmission through aerostat material", Aerostat Systems Department, TCOM Corporation, Serial no. 831986.*
3. *Tripathy, A., SARANGI, S. K., & PANDA, R. (2013). Fabrication of functionally graded composite material using powder metallurgy route: an overview. International Journal of Mechanical and Production Engineering Research and Development (IJMPERD), 7(6), 135–146.*
4. *M. A. F. Fernandes, N. P. Yelve, R. S. Pant, "Leak Testing of Envelopes of LTA SYSTEM", IIT Bombay.*
5. *K. Kammermeyer and D. W. Brubaker, "Permeability Tester", State University of Lowa, Lowa city, June 12, 1953, Serial No. 361202.*
6. *J. M. Doyle, "Permeability of noble gases through Kapton, butyl, nylon, and ''Silver Shield'' Department of Physics, Harvard University, xfordSt., Cambridge,19 January 2010, Serial no. 267271.*

7. *Kanimozhi, K., & Rabi, B. R. M. Design Fabrication and Control of A Hexapod Robot.*
8. *X. F. Yao, Y. M. Lei, C. Xiong & Q. Wu, "Mechanics Analysis on Helium Leakage of Flexible Composites", Tsinghua University, Beijing, China, 05 sept. 2012, Serial no. 603–612.*
9. *Abdullah, M. M., Mohammed, G. H., Hussein, M. M., & Aadem, K. A. Fabrication and Studying The Characteristics of Ito/Cdte/Si/Au Thin Film Solar Cell.*
10. *L. J. van Rooyen, J. Karger-Kocsis, O. C. Vorster, and L. D Kock "Helium gas permeability reduction of epoxy coatings by incorporation of glass flakes," Journal of membrane science, 2013, pp.203–210.*
11. *E. L. Crosby, "Apparatus and method for measuring permeability", RCA Corporation, New York, Oct. 22, 1976, Serial no. 734728.*
12. *P. S. Sorce, "Method and apparatus for measuring the permeability of the material", The ARO Corporation, May 31, 1983, Serial No. 4385517.*
13. *Gupta, A. N. S. U. I. A., Kaur, D. A. M. A. N. P. R. E. E. T., Gingh, G., & Duggal, A. A. K. A. S. H. (2017). Tooth Supported Mandibular Overdenture: A Forgotten Concept.*
14. *P. W. Johnson, J. F. Stampfer, "Universal penetration test apparatus with fluid penetration sensor", University of California, Feb. 02, 1999, Serial No.5866801*
15. *W. Kang, Y. Suh, K. Woo, In Lee, "Mechanical property characterization of film-fabric laminate for stratospheric airship envelope", Korea Aerospace Research Institute, Republic of Korea, 5 June 2006, Serial no. 305333.*
16. *D. Limb, "Helium, its Recovery, Purification, Transport and Deployment as an Airship Lifting Gas", University of Manitoba Smart Park, Canada, April 3, 2009. Airship Lifting Gas", University of Manitoba Smart Park, Canada, April 3, 2009.*
17. *Design of Machine Elements V. B. Bhandari, Tata McGraw-Hill Education, 2010.*

APPENDIX

- Definition of ppm: $1ppm = \frac{1\mu moleofgas}{1moleofair}$
- At NTP i.e. 1 bar pressure and 32 $°C$ temperature: $1moleofgas = 25.12L$
- $1\frac{mbarL}{s} = 2 \times 10^4 \frac{L}{m^2 day}$